Hyperspectral opportunities with next-generation QSIP Arrays

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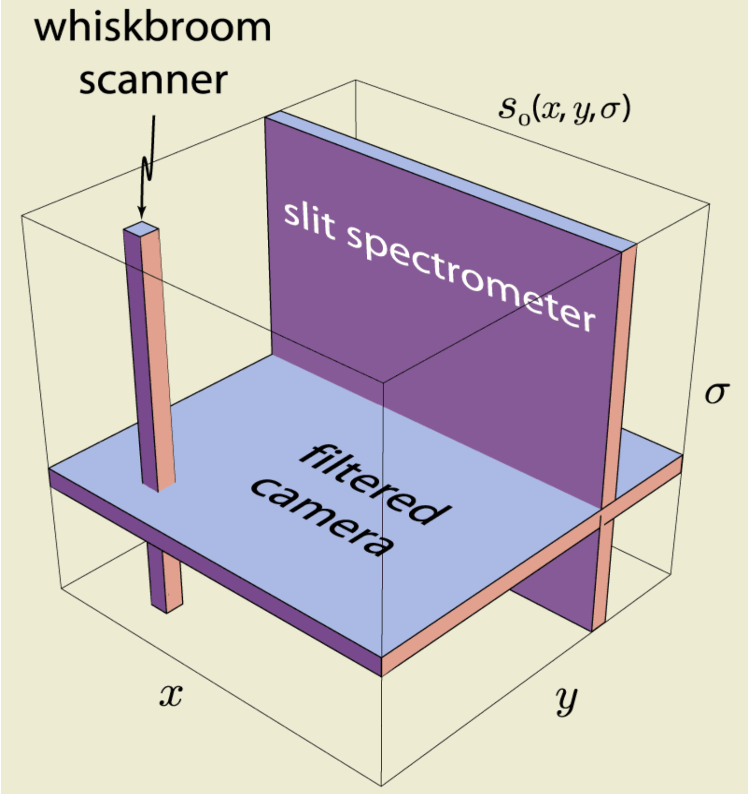
Review: The 3-D hyperspectral data cube & Various ways to acquire it

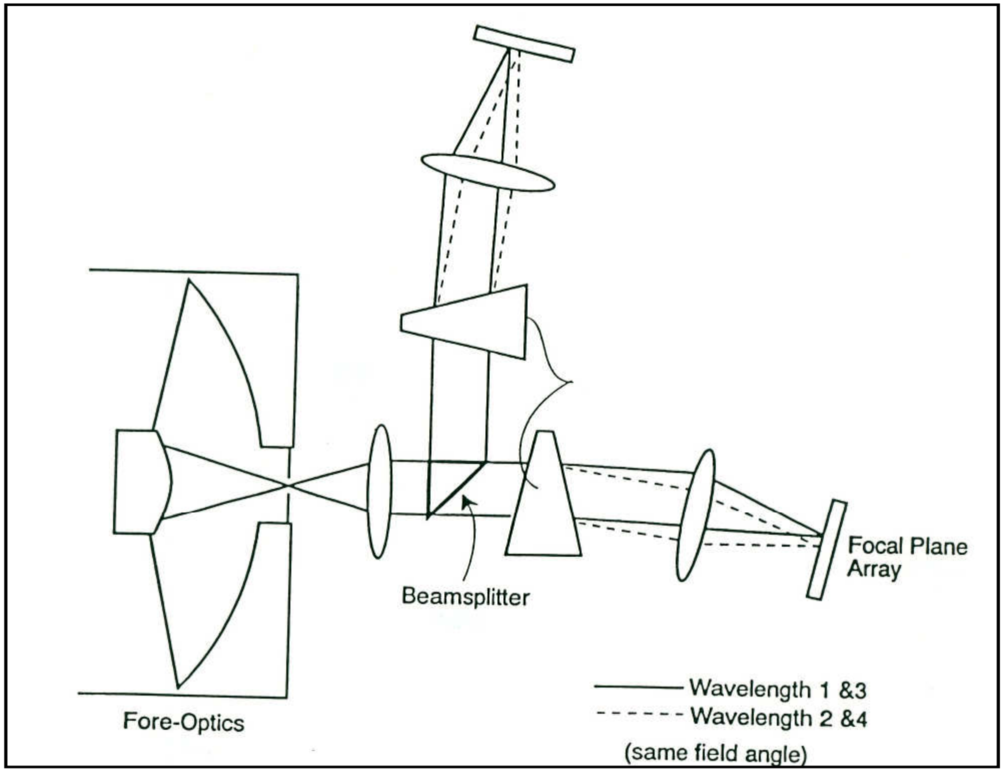


Courtesy U.A., Prof. Dereniak

At least one approach, the Computed Tomographic Imaging Spectrometer (Dereniak, U. Arizona), acquires spectral & spatial data on an entire scene as a single frame of FPA – but most approaches scan in one or more dimensions.

Classical "dual channel" IR spectrometer

"Channels" share a common aperture and FOV through the use of optical beamsplitter



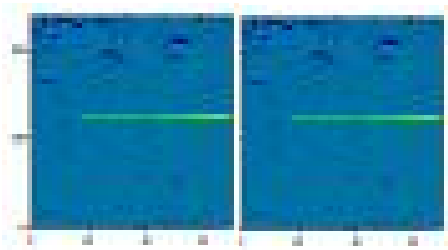
Each channel optimized for an approximate octave in wavelength

- **Multi-channel configuration with paired dispersion elements and FPAs:**

  - Provides dual-waveband coverage, but complexity, volume, alignment challenges remain

Grating-based hyperspectral imaging with Multi-waveband FPA technologies – MWIR & LWIR

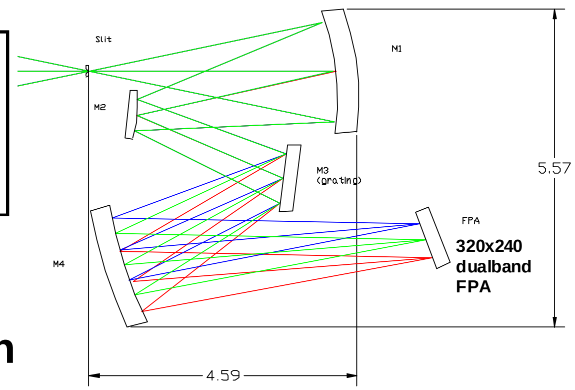
MWIR LWIR



(Greybody point source spectra)

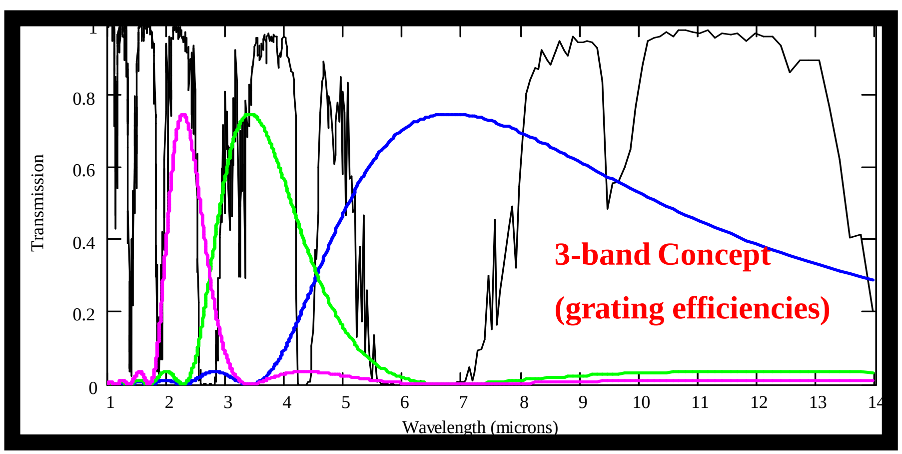
- **Overcomes challenges of "Traditional" MWIR & LWIR Spectrometers**
  - **Single FPA (dualband); single grating (2 orders)**
  - **Misalignments, higher mass, volume, power consumption, & cooling all minimized**

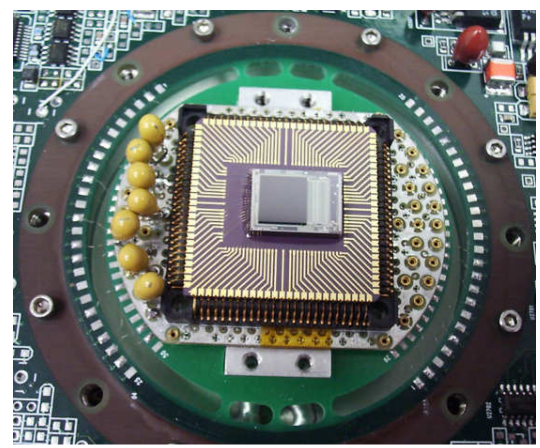
Use of two, overlapping grating orders with dualband FPA results in high efficiency over broad wavelength range



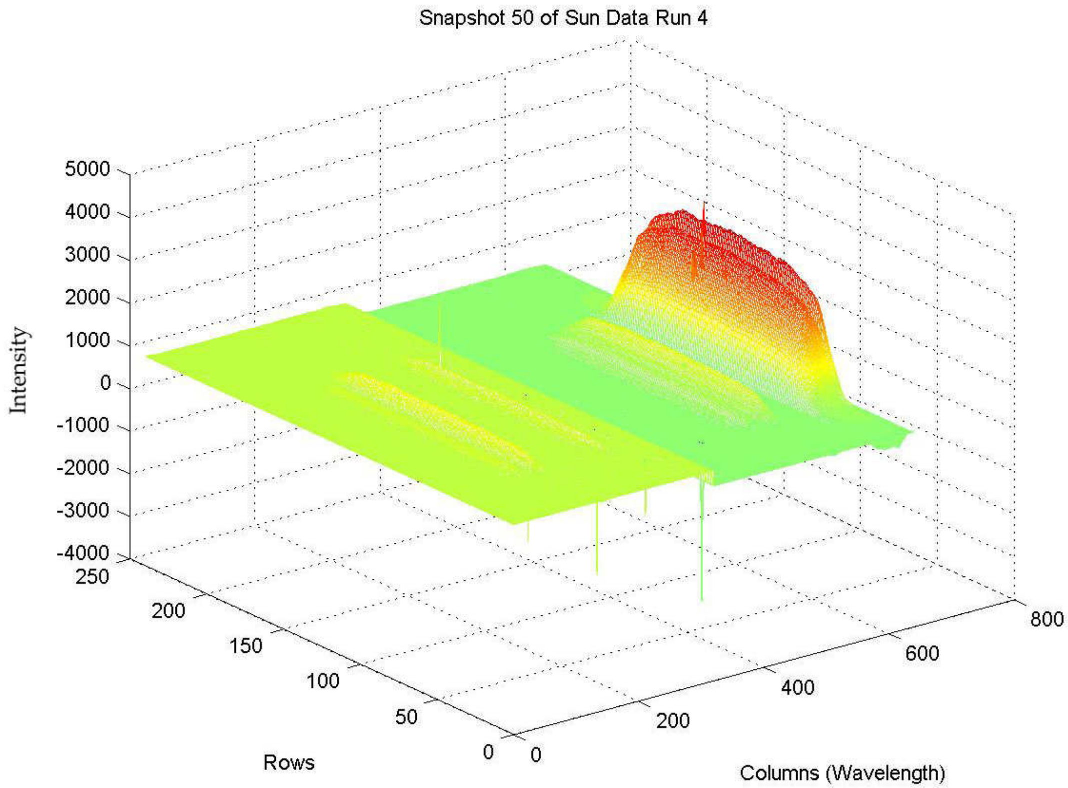
- **Payoff**
  - **Reduced complexity**
  - **Perfect alignment & reduced cooling overhead**
  - **Simpler processing; perfect spectral image registration**

Atmospheric transmission





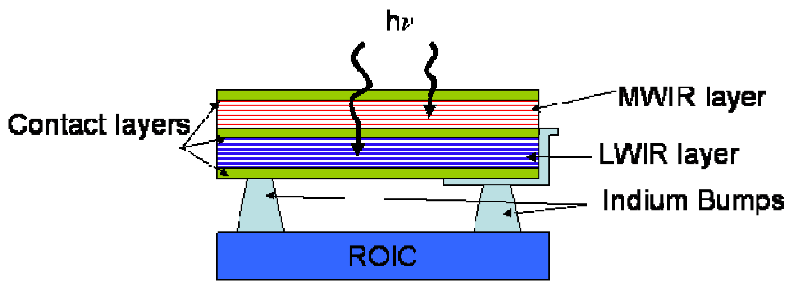
Spectral images; dualband FPA & Grating used in two orders



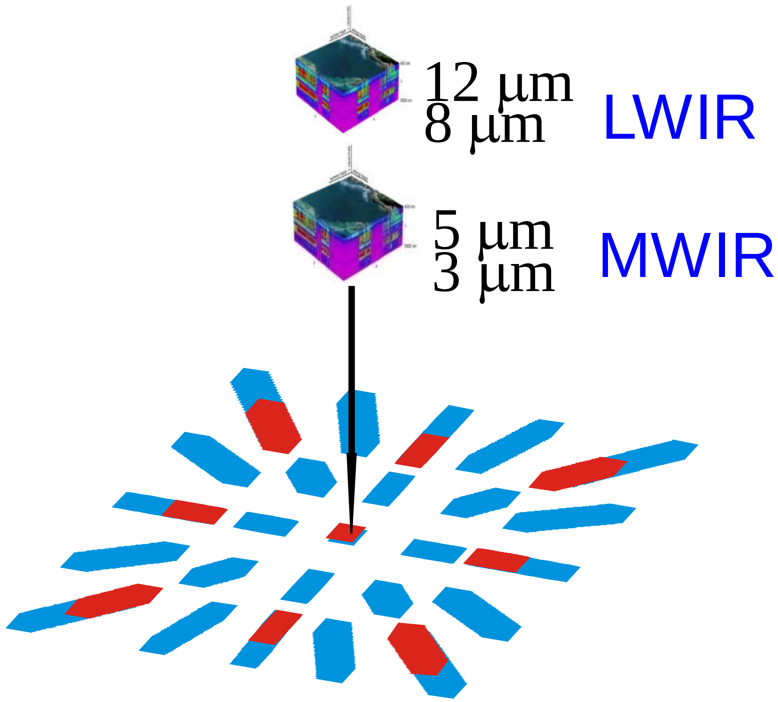
- **MWIR & LWIR hyperspectral image acquired with a dualband FPA, with wavelength decreasing with increasing column number. (Discontinuity near Column 320 corresponds to gap in wavelength between the two spectral regions.)**
- **~ 3.5 to 6 microns, and 7 to 12 microns**

Dual Band CTIS System - Motivation

- **Investigate two separate spectral regions of the same scene, over bandpass wider than one octave.**
- **Accurately co-register over the broadened spectral region.**
- **Use dualband FPA (schematic below)**



Computer-generated holographic, transmission grating



(Courtesy LtCol John Hartke, USMA)

A potential QSIP approach for hyperspectral, at the pixel level of a 2-D FPA

Review dispersive properties, with depth, of Photovoltaic Detector

The linear dispersive properties of the $L(\lambda)$ function (absorption length), given the absorption coefficient $a(\lambda)$, are described by

$$dL(\lambda)/d\lambda = -[1/\ a^2(\lambda)]\ da(\lambda)/d\lambda.$$

We illustrate the dispersive properties for a simplified approximation of $a(\lambda)$ for HgCdTe,

$$a(\lambda) \sim \sqrt{}[(hf/e_{gap})^2 - 1]. \qquad (f = c\ /\ \lambda)$$

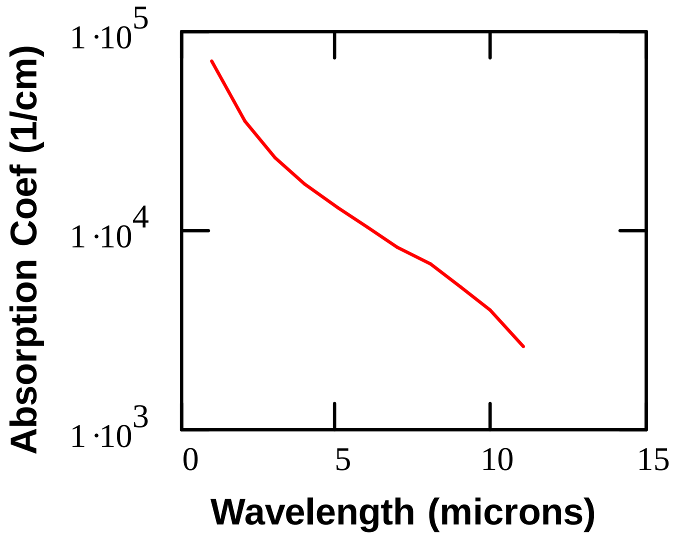
… which allows a simplified approximation as

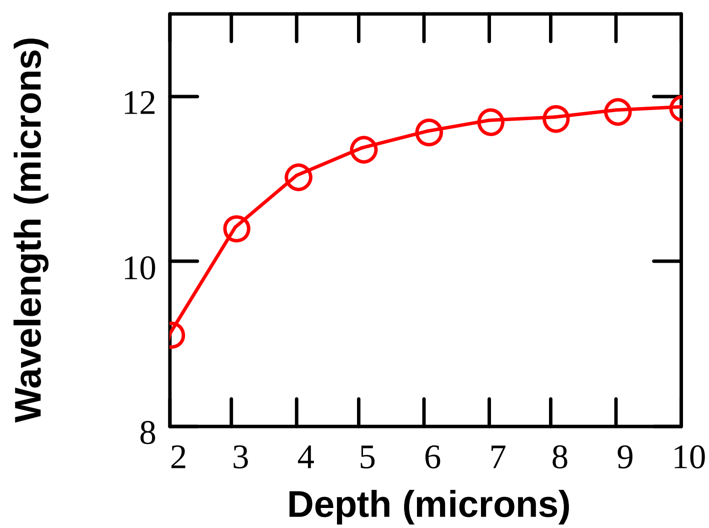
$$(dL(\lambda)/d\lambda\ )^{-1} = \lambda a(\lambda)[1 - (e_{gap/}\ hf)^2\ ].$$

This equation relates most directly to the depth-dispersive properties of the material. It is interesting to ask about the level of dispersion for a hyperspectral application in, e.g., the 10 micron wavelength region. For example, if it were to become possible to create p-n diodes at a separation Δ along the edge of a structure whose top surface were exposed to infrared radiation, what would be the corresponding separation of wavelengths defined by the $L(\lambda)$ function?

($e_{gap,}$ h, & ϕ are photovoltaic energy gap, Planck's constant, frequency of light, resp.)

L(λ) as a function of depth





The modeled absorption coefficient (left, for 12 micron cut-off HgCdTe) is the basis for the modeled "dispersion" (of λ in L(λ), the absorption length) as a function of depth, shown on the right.

(N.B., 63% of radiation absorbed *over* the depth, L(λ).)

Highly dispersive materials have large values of a(λ) and smaller values of its derivative. However, in the vicinity of the band edge of HgCdTe, the overall dispersion is made small by the additional multiplicative factor.

Summary for QSIP hyperspectral

- Improved dispersion (HgCdTe example) would require composition gradient, and bandgap narrowing with depth
  - Somewhat analogous to dualband detector array layers, for which an LWIR layer is epitaxially grown onto an MWIR layer, and the overall architecture then used in a back-illuminated mode.
  - How slowly should composition vary with depth to spatially differentiate the wavelength intervals?
  - What type of differential subtraction of the photocurrents, arising from different depths, would be necessary to “see” a predominance of longer wavelengths at deeper depths?
  - And, most importantly, what sort of interconnects would one employ to access photocurrent over the range of depths, for each pixel in a two-dimensional array?
- QSIP analog
  - Implants along vertical wall of pixel to collect photocurrent at different depths?
  - Multi-conductor, coaxial vias or related nano-technologies?

Conclusions

- **Although challenging, hyperspectral at the pixel level may be possible with new QSIP architectures, combined with nano-engineering technologies making possible such ideas as concentric vias with many isolated conduction paths, or even the implanting of electrical contacts along the height of each pixel in an array.**
- **Other QSIP attributes would also be beneficial**
  - **Lower dark currents at higher operating temperatures**
  - **QWIP-like separation of wavebands over a continuum of wavelengths**

Thanks for your attention,

Questions?